

APPLICATION  
FOR  
UNITED STATES PATENT

TITLE OF INVENTION  
  
**ULTRAVIOLET AIR PURIFIER**

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## ULTRAVIOLET AIR PURIFIER

### Cross-Reference to Related Applications

This application is a continuation-in-part application of co-pending U.S. Serial No. 09/336,470, filed June 18, 1999, that is hereby incorporated herein by reference.

### 5 Field of the Invention

The present invention relates to air purifying devices that employ ultraviolet radiation to destroy microorganisms and remove odors and other impurities from the air.

### Background of the Invention

10 Today, a large number of pollutants can be found in the air and water. Among the various harmful air pollutants that exist in the air that people breath are pollen, lung damaging dust, smoke and bacteria. Other pollutants include various organic vapors and toxic gases. The environment is often contaminated with a variety of noxious and toxic gases including carbon monoxide, methane, sulphur dioxide, hydrogen sulfide and a broad variety of organic vapors. Some of these are widely prevalent in the environment, particularly in  
15 urban areas, and others tend to be pronounced in homes, offices, or other confined spaces due to activities within those spaces. Noxious or toxic materials may be produced from tobacco smoking, cooking, open fireplaces, faulty appliances, or a variety of other normal activities. Some of these are merely unpleasant because of odors while others such as carbon monoxide can be dangerous. Because these pollutants are so prevalent in the air and are found in most  
20 locations, contact with them is inevitable.

Typically, air pollutants cause general discomfort to many people, and can be particularly troublesome to individuals that suffer from emphysema, asthma, and hay fever and like allergies. It has also been found, for example, that a high proportion of homes have unsuspected carbon monoxide concentrations which contribute to vague disorders such as  
25 lassitude and headaches at concentrations far below levels that produce overt symptoms of toxicity. Hence, apparatus and methods for removing air pollutants from the air and/or sensing the presence of pollutants have wide spread economic and therapeutic appeal.

Air purifiers are generally known and exist. A typical air purifier includes a housing having a chamber mounting an ultra-violet (UV) lamp. Air is drawn into the bottom of the housing and passes through the chamber where it is exposed to UV radiation emitted from the lamp, which denatures organic proteinous particles, e.g., exterminates microorganisms, that are carried in the air. The air is then discharged from the housing top to the external environment. One prior art air purifier is shown and described in U.S. Patent No. 4,210,429 of Golstein. The Golstein air purifier employs a UV lamp, which is mounted in a germicidal chamber to exterminate microorganisms that are carried in the incoming flow of air. A charcoal filter is seated above the germicidal chamber and removes odors from the UV radiation exposed air.

Another prior art air purifier is disclosed in U.S. Patent No. 4,621,195 of Larsson. Larsson also describes an apparatus for destroying microorganisms by irradiation with UV light emitted by a UV lamp supported in an irradiation chamber. The irradiation chamber is segregated into a set of minor chambers by a number of partition walls. The partition walls have formed therein air-flow openings that are oppositely located relative to the openings formed in the adjacent partitions. This alternating arrangement of air-flow openings maximizes the amount of time the air remains in the irradiation chamber in order to maximize the amount of microorganisms destroyed.

Photocatalytic systems such as the one disclosed in U.S. Patent No. 5,835,840 to Goswami also seek to improve indoor air quality. In the Goswami system, a reactor is provided in which UV lamps are installed such that surfaces coated with a semiconductor catalyst (e.g.,  $\text{TiO}_2$ ) are exposed to UV radiation as air passes over the surfaces. The combination of the absorption of the UV light photons by the catalyst in the presence of water molecules in the air leads to the creation of hydroxyl radicals, which, in turn, cause the destruction of chemical and microbiological contaminants in the air.

There still exists a need in the art for improved air purifiers that can exterminate microorganisms in the air as well as reduce or eliminate odors. In particular, a compact, inexpensive air purifier that is relatively easy to manufacture would represent a major improvement in the art.

## Summary of the Invention

The present invention concerns air purifiers and methods of purifying air by incorporating a titanium element within an ultra-violet irradiation chamber. Titanium and its alloys develop a thin, tenacious and highly protective surface oxide film. The surface oxide of titanium will, if scratched or damaged, immediately reheal and restore itself in the presence of air or even very small amounts of water. This oxide layer, in the presence of ultraviolet radiation and air, will promote photocatalysis.

The present invention also pertains to an air purifier and methods for purifying air by employing ultraviolet radiation with differing energy spectra. The air purifier may include an ultraviolet (UV) generator comprised of one or more radiation sources, that define distinct radiating regions that may be optically isolated from each other. In this system, one or more surfaces within the radiating regions comprise titanium or a titanium-rich alloy, which have a naturally oxidized surface. The air purifier photocatalytically treats air with various combinations of ozone-producing radiation, cell wall-destroying germicidal radiation and antimicrobial radiation, which may be emitted from any of the radiating regions of the radiation system. The naturally oxidized surface containing titanium dioxide absorbs the UV light photons and, in the presence of water molecules in the air, creates hydroxyl radicals, which, in turn, causes the destruction of chemical and microbiological contaminants in the air.

The air purifier of the present invention includes a housing having an irradiation chamber, an air inlet for introducing air into the irradiation chamber, and at least one radiation source disposed within the irradiation chamber. Also within the chamber (or the inlet), a titanium element is disposed such that air passing through the purifier device will flow over or along this titanium element. The radiation source or sources are generally one or more lamps, each of which is capable of producing one or more predetermined bands of UV radiation in the range of about 160 nm to about 360 nm. A particularly effective UV radiation for photocatalytic treatment has a wavelength of approximately 254 nm.

5 In one embodiment of the present invention, a single radiation source with distinct radiating or radiation regions is provided in the air purifier. One of these radiating regions may emit a wavelength between about 160 nm and about 200 nm that is effective to ionize oxygen in the air being treated into ozone, while another distinct radiation region may emit a wavelength between about 230 nm and about 280 nm that is effective to destroy the cell walls of active ingredients such as spores and fungi in the air being treated. In one embodiment, the titanium catalyst is disposed in the first (ozone generating) region. In others, titanium catalytic elements can be disposed in a plurality of regions. Treatment of air by both of these radiation regions of the radiation source results in the production of free radical oxygen atoms that, in turn, convert carbon monoxide in the air being treated into carbon dioxide, and which also help reduce the toxicity of volatile organic compounds contained in the air being treated by oxidizing the volatile organic compounds.

15 It is to be understood that a plurality of radiation sources may be provided in the air purifier. Each radiation source can be divided into at least two radiating regions, one of which generates a first energy maximum of ozone-producing radiation and a second, separate energy maximum of germicidal radiation and, optionally, a third separate energy maximum of radiation each as described above with respect to the single radiation source embodiment of the present invention. Again, the titanium catalysts can be disposed in each of the regions or only in one region.

20 The radiation sources may have even more than two radiating regions, wherein the additional radiating regions may produce either an additional wavelength between about 160 nm and about 200 nm that is effective to ionize oxygen in the air being treated into ozone, or an additional wavelength between about 230 nm and about 280 nm that is effective to destroy the cell walls of active ingredients such as spores and fungi in the air being treated, or a wavelength of between about 330 and about 360 nm that is effective to reduce the toxicity of volatile organic compounds by oxidizing the volatile organic compounds.

Alternatively, the radiation sources can each be a dedicated source, primarily emitting radiation within a single radiation band with a single energy maximum.

30 Generally, the radiation regions will have lengths with respect to each other that approximately correspond to their wavelength relationships, such that the radiation region

which produces the longest wavelength will have the largest region length. Likewise, the radiation region which produces the shortest wavelength will generally have the smallest region length. In a preferred embodiment, the titanium catalyst is disposed within the chamber at a location where it is directly exposed to UV radiation in at least one region.

5           The air purifier may further include an air inlet and an air outlet also formed in the housing for collecting and discharging air, respectively. Moreover, each radiation region of each radiation source may be optically isolated from each of the other radiation regions of all of the radiation sources such that each radiation region is prevented from producing radiation that may interact with or "see" radiation from any of the other radiation regions of any of the  
10       radiation source(s). This optical isolation may be effected by the placement of structural optical isolator(s) such as baffles or barriers or a combination thereof in predetermined locations with respect to the radiating regions of the radiation sources. The optical isolator can be formed in part or wholly from titanium (e.g. a thin sheet or foil of titanium). This foil may preferably have a thickness of between about 0.030 inch to 0.050 inch. In other  
15       embodiments, radiation source(s) are mounted either individually or in groups to brackets made from titanium foil or sheet.

Also, a predetermined fraction of the inside surface of the irradiation chamber of the air purifier and/or the surfaces of the optical isolator can be made of one or more elements or compounds and/or coated with one or more elements or compounds in order to catalyze the  
20       reactions caused by the interactions between the wavelengths produced from the radiating regions and air pollutants, microorganisms and other airborne targets of the air purifier.

A first energy maximum may occur at a first relative maximum of the total radiation source energy output that is in the range between about 160 nm and about 200 nm and represents radiation that is effective to ionize oxygen in the air being treated into ozone. A  
25       second energy maximum may occur at a second relative maximum of the total radiation source energy output that is in the range between about 230 nm and about 280 nm and that is effective to destroy the cell walls of active ingredients such as spores and fungi in the air being treated. Further, a third energy maximum of the total radiation source energy output may occur in the range between about 330 nm and 360 nm that is effective to reduce the  
30       toxicity of volatile organic compounds. These energy maxima, alone and in concert, act to

convert portions of air treated in the air purifier to free radical oxygen ions that, in turn, help convert carbon monoxide in the air being treated into carbon dioxide, as well as help reduce the toxicity of volatile organic compounds in the air being treated by oxidizing the volatile organic compounds.

- 5           The air purifier may further include a heater mounted within the housing that generates heat, a cooling element mounted within the housing for generating and providing to the external environment cool air, and a filter element, mounted within the purifier, for filtering the air.

- 10           According to another embodiment of the invention, the air purifier includes a housing element having an irradiation chamber, an air inlet for allowing air to enter into the housing, an air outlet for allowing air to exit the housing, an air passage element for introducing air into the irradiation chamber and for moving air out of the chamber, and at least one titanium catalyst.

- 15           The present invention further encompasses a system for purifying air. The system includes a housing element having an air inlet, an air outlet, and an irradiation chamber, an air introduction element that introduces air into the irradiation chamber, a titanium catalyst, and at least one radiation source, mounted within the irradiation chamber, that generates UV radiation having first and second energy maxima within a pair of wavelength intervals. The system further includes a power supply element that supplies power to the air introduction  
20           element and the lamp element.

The system can further include a timer element, mounted on the housing, for allowing a user to select a time period in which power is supplied to the lamp. The system can further include a heater, a cooling element, and a filter element, all mounted within the housing.

- 25           According to other aspects of the air purifying system, the air introduction means is a blower and the power supply element includes a ballast.

The method of the present invention includes providing a housing having an air inlet and an irradiation chamber, with a titanium element disposed therein. Activation of at least one radiation source within the chamber induces a photocatalytic reaction causing a reduction in pollutant level in the air passing through the chamber. Kinetics for this reaction are





According to one aspect, the system further includes a gas detection element, associated with the housing, for detecting the presence of one or more gases in the air.

According to one practice of the invention, the gas detection element generates a gas output signal indicative of the presence of the gas in the air. The gas detection element employed in the present invention can detect the presence of most harmful organic gases, such as carbon oxides, benzene, methane, formaldehyde, sulfur dioxide, oxygen, hydrogen, hydrogen sulfide, NO<sub>x</sub>, ozone and aerosols, and other harmful and/or toxic vapors including organic vapors.

According to another aspect, the system further includes a power element for selectively supplying power to the housing, and thus to the lamp, in response to the gas output signal. The power element is preferably in electrical communication with the at least one radiation source and the gas detection element.

The invention will next be described in connection with certain preferred embodiments. However, it should be clear that various changes and modifications can be made by those skilled in the art without departing from the spirit and scope of the invention. For example, various housings having differing shapes can be employed to house the lamp.

#### **Brief Description of the Drawings**

The foregoing and other objects, features, aspects and advantages of the invention will be apparent from the following description and apparent from the accompanying drawings, in which like reference characters refer to the same parts throughout the embodiments and different views. The drawings illustrate principles of the invention and, although not to scale, show relative dimensions.

FIG. 1 is a plan view of a first embodiment of an air purifier according to the invention;

FIG. 1A is an enlarged view of section 1A of the air purifier of FIG. 1, in accordance with an embodiment;

In accordance with a further embodiment, FIG. 1B is an enlarged view of section 1A of the air purifier of FIG. 1 illustrating use of a titanium catalytic element as a bracket to which an ultraviolet lamp (radiation source) is mounted;

FIG. 2 graphically illustrates the relative maximum wavelengths of radiation produced by the radiation source housed within the air purifier of FIG. 1 according to a preferred embodiment of the invention;

FIG. 3 is a plan view of an air purifier according to a second embodiment of the invention;

FIG. 3A is a plan view of an embodiment similar to that of FIG. 3 illustrating use of a titanium element 41 as a bracket for the ultraviolet lamp 40;

FIG. 4 is a plan view of the air purifier of FIG. 2 which mounts a heat exchanger;

FIG. 4A is a plan view of an embodiment similar to that of FIG. 4 illustrating use of a titanium element 41 as a bracket for the ultraviolet lamp 40;

FIG. 5 is a plan view of the air purifier of FIG. 3 which mounts an air conditioning condenser;

FIG. 5A is a plan view of an embodiment similar to that of FIG. 5 illustrating use of a titanium element 41 as a bracket for the ultraviolet lamp 40;

FIG. 6 is a plan view of a third embodiment of an air purifier according to the invention;

FIG. 6A is a plan view of an embodiment similar to that of FIG. 6 illustrating use of a titanium element 41 as a bracket for the ultraviolet lamp 40;

FIG. 7 is a plan view of an air purifying and gas detection system in accordance with the present invention;

FIG. 8 is a plan view of a second embodiment of the air purifying and gas detection system of FIG. 7;

FIG. 9 is a plan view of another embodiment of an air purifying device according to the invention;

FIG. 9A is a plan view of an embodiment similar to that of FIG. 9 illustrating use of a titanium element 41 as a bracket for the ultraviolet lamp 40;

5        FIG. 10 is a plan view of a third embodiment of the air purifying device according to the invention;

FIG. 10A is a plan view of an embodiment similar to that of FIG. 10 illustrating use of a titanium element 41 as a bracket for the ultraviolet lamp 40;

10       FIG. 11 is a plan view of an alternate embodiment of the radiation source of both the air purifier of FIGS. 1 and 3-6 and the air purifying device of FIGS. 7;

FIG. 11A is a plan view of an embodiment similar to that of FIG. 11 illustrating use of titanium elements 41 to separate four ultraviolet lamps, but without optical isolator elements separating radiating regions;

15       FIG. 12 is a graphical representation of the removal of toluene from the air as a function of time with exposure to UV in an air purification system in accordance with the present invention;

FIG. 13 is a graphical representation of the removal of toluene from the air as a function of time without exposure to UV in an air purification system in accordance with the present invention;

20       FIG. 14 is a graphical representation of the inactivation of *E. Coli* in air as a function of time with exposure to UV in an air purification system in accordance with the present invention;

FIG. 15 is a graphical representation of the inactivation of yeast in air as a function of time with exposure to UV in an air purification system in accordance with the present invention; and

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FIG. 16 is a graphical representation of the removal of acetone from the air as a function of time with exposure to UV in an air purification system in accordance with the present invention.

### **Detailed Description**

5           The present invention includes an air purification system that, in an embodiment, includes an irradiation chamber through which air passes. A titanium element resides within this chamber; the element may be a wall or other structure to which circulating air is exposed. The combined effect of passing impure air over such an element that has a naturally occurring titanium dioxide surface and of exposing this air to UV radiation catalytically  
10       favors the creation of hydroxyl radicals, which, in turn, cause the destruction of chemical and microbiological contaminants in the air. When a solid semiconductor catalyst, such as titanium dioxide, is illuminated with greater-than-bandgap ultraviolet or near ultraviolet light, electron excitation occurs within the solid. Electron-hole pairs generated by the photoexcitation can then react with water or oxygen to lead to the formation of hydroxyl and  
15       other oxygen-containing free radicals. These radicals are then free to attack and oxidize organics such as chemical and microbiological contaminants in the air.

FIG. 1 shows an embodiment of an air purifier 10 according to the present invention. For purposes of clarity, the internal components of the air purifier throughout the figures are shown. The air purifier 10 includes a housing 12 that has a front wall 14, a pair of sidewalls  
20       16, and a rear wall 18. The front and rear walls 14, 18 have a baffle plate 20 formed thereon. A base 22 supports the front, side and rear walls 14, 16 and 18, and a top cover 24 having an air outlet 26 defining an air outlet passageway encloses the purifier 10.

The housing 12 mounts a substantially horizontal divider plate 28 and a pair of vertically extending shield plates 29. Preferably, the shield plates 29 are spaced from the  
25       baffle plates 20 and extend along the front and rear walls a selected distance sufficient to cover the baffle plates 20. The divider plate 28 and the shield plates 29 separate the interior of the housing into an air intake chamber 30, an eradication chamber 31, and an air discharge chamber 32. The shield plate 29 channels the intake air from the intake chamber 30 into the eradication chamber 31, and further provides a barrier between the external environment and  
30       the glare of a UV lamp mounted within the purifier, as described below.

1 The divider plate 28 includes an opening 34 formed at one end of the plate that allows  
2 air to flow between the eradication chamber 31 and the air discharge chamber 32. In the  
3 illustrated purifier 10, the opening 34 has a substantially rectangular shape. The baffle plates  
4 20 are in fluid communication with the air intake chamber 30, and, in combination, provide  
5 an air intake passageway between the external environment and the interior of the purifier.

6  
7 The air purifier 10 mounts a fan 36 in the air discharge chamber 32. The air purifier  
8 10 includes a UV generating system of one or more radiation sources. In the embodiment  
9 depicted in FIG. 1, the UV generating system includes one radiation source 40. The radiation  
10 source 40 is supported within the eradication chamber 31, beneath the divider plate 28 and is  
11 in electrical communication with a power supply 38. The radiation source 40 is shown in  
12 FIG. 1 as a UV lamp, but may be provided as any radiation source that is capable of  
13 producing UV radiation in the range of about 160 nm to about 360 nm. The power supply 38,  
14 which preferably includes a ballast and a transformer, is a conventional item and is  
15 commercially available through Robertson Transformer Co., Illinois, U.S.A.

16 The UV lamp 40 may have two contiguous and integrally formed UV radiating or  
17 radiation region. According to one embodiment, in the region of FIG. 1 denoted 1A  
18 (illustrated in FIG. 1A), UV lamp 40 has two radiating regions, 40A and 40B, which are  
19 physically separated from one another by an optical isolator 41 which is effective to optically  
20 isolate each radiation region.

21 For example, radiating region 40A may produce germicidal radiation within a selected  
22 band sufficient to kill microorganisms, such as airborne and surface bacteria, viruses, yeast  
23 and molds that are carried in the incoming air. Radiating region 40B may produce ozone  
24 generating radiation. In an embodiment of the air purifier 10 of FIG. 1 where the UV lamp  
25 40 has greater than two radiating regions, each additional radiating region may produce either  
26 germicidal radiation within a selected band sufficient to kill microorganisms, such as airborne  
27 and surface bacteria, viruses, yeast and molds that are carried in the incoming air, or may  
28 produce ozone generating radiation, or may produce antimicrobial radiation that is effective  
29 to reduce the toxicity of volatile organic compounds.

30 Regardless of the number of radiating regions into which the UV lamp 40 is divided,  
31 the radiating regions function individually and in concert. For example, as is known, ozone

5 serves as a deodorizer by removing odors from the air, and further functions as a redundant germicidal radiation generator by also producing radiant energy sufficient to destroy microorganisms. The germicidal radiation produced by radiating region 40A further limits the amount of ozone that escapes from the air purifier 10 by reacting with the ozone generated by the radiating region 40B to produce atomic oxygen and oxygen free radicals.

10 In another embodiment, illustrated in FIG. 1B, lamp 40 is shown attached to mount 41; mount 41 is preferably formed from titanium to enhance the desired photocatalytic effect to create free radicals. Regions 40A and 40B may, in this embodiment, constitute only a single radiating region; the radiation generated by lamp 40 is preferably of wavelength approximating 254 nm. The production of free radicals is increased due to the presence of titanium mount element 41 (FIG. 1B).

15 Element 41 also is configurable (e.g. FIG. 1A) to optically isolate each lamp (when multiple lamps are used) from one another. FIG. 1A shows an enlarged view of such an optical isolator 41. The optical isolator 41 should be made of a material through which the UV radiation produced by the UV lamp 40 cannot travel, but around which air may travel. Additionally, the optical isolator 41 may be shaped and positioned (FIG. 1A) such that the radiation produced from each radiating region 40A, 40B is optically isolated from all other radiation regions of the radiation source. The optical isolation of each radiating region is beneficial because it allow each of the regions which prevents one wavelength from interfering with a different wavelength, thus allowing each wavelength to maximally affect the air being treated.

20 One of ordinary skill in the art will realize that the optical isolator may be made of different materials, such as aluminum, lead, steel or titanium, as long as the optical isolator is effective to optically isolate each radiating region from all other radiating regions while still being effective to allow air to circulate through the air purifier and be properly exposed to, and treated by, each radiating region of the radiation source 40.

30 The term "titanium" as used herein is intended to encompass "pure" titanium and titanium-rich alloys that inherently form natural, tenacious, self-replenishing titanium oxide surface layers. The percent (by wt.) of titanium in such titanium-rich alloys is preferably to be at least 50 percent.

For example, if element 41 is made, in whole or in part, of titanium, then air that passes through the air purifier 10 and over the titanium element 41 will, in the presence of the emitted UV radiation(s) undergo a photocatalytic reaction. The titanium catalyst 41 will assist in breaking down the constituents of the air to create oxide ions and/or hydroxyl radicals that will convert carbon monoxide in the air to carbon dioxide, and increase the destruction and/or reduction of the levels of bacteria, virus, mold, mildew, fungus and volatile organic compounds in the air by, for example, oxidizing them and/or causing the formation of water vapor. It should be appreciated that the titanium catalytic elements of the present invention will naturally oxidize and present a surface layer of mixed titanium oxides and related compounds. It is this oxide-rich surface that provides, to a large degree, the photocatalytic effect. Unlike the inherently limited-life titanium dioxide coating suggested in the art, the titanium catalysts of the present invention provide a self-renewing surface as catalyst.

Element 41 may also be coated with other elements and/or compounds in order to more effectively and/or more efficiently reduce or destroy unwanted components of the air being treated by the air purifier 10. Among these elements or compounds are silver compounds or oxides and copper compounds or oxides, platinum or gold. These compounds may be applied to the air purification system via a coating either on, near or entirely separate from element 41. The presence of these elements or compounds will assist any photocatalytic reactions taking place in the air purifier 10 as summarized in the teachings of U.S. Patent Nos. 5,759,948 to Takaoka et al. and 5,835,840 to Goswami, both of which are expressly incorporated by reference herein.

Oxides of titanium provide particularly effective coatings designed to promote photocatalysis. Significant enhancement of the photocatalytic reactions that take place as air flows over such a coating in the presence of ultraviolet radiation is thought to occur irrespective of which of the various crystallographic forms of titanium oxide is used. As a result, element 41 and/or other surfaces exposed to the air within air purifier 10 on, near or entirely separate from element 41, in an embodiment, are fabricated from elemental titanium metal or a titanium-rich alloy.

Commercially pure titanium is an excellent oxygen getter under most environmental conditions. As a result, titanium and titanium-rich alloys naturally maintain an oxide-containing film upon its metallic surface. Adherence of this surface film is particularly tenacious. Further, this oxide-containing surface layer will tend to reform as it is used up and fresh metallic surfaces are exposed to the air as the chemical reactions with the air and impurities therein proceed. Thus, these parts of air purifier 10 may only require infrequent cleaning or replacement.

The UV lamp 40 emits UV radiation having first and second and, optionally, third energy maxima. The term “first and second and, optionally third energy maxima” is intended to include the maximum radiation lamp output values, as defined by the total output radiation producing capabilities of the lamp, which occur within selected intervals or band of wavelengths. Preferably, the lamp 40 produces a maximum energy value within a wavelength interval or band at about 254 nm.

Each radiating region 40A, 40B produces at least one energy maximum lamp output value within a selected wavelength band at a selected maximum wavelength. Each maximum energy lamp output value can be either a relative or local maximum value or an absolute maximum value of the total lamp output. Those of ordinary skill will readily recognize that the maximum energy value of the lamp output of each radiating region is a function of the relative size of the radiating region in comparison to the total size of the lamp. For example, the first maximum energy value of the radiating region 40B depends upon the desired amount of ozone-producing radiation to be produced by the lamp.

In exemplary embodiments of the invention, the radiating regions 40A, 40B have lengths such that radiating region 40A is longer than radiating region 40B. Generally, the combined length of radiating regions 40A and 40B is between about 6 and 11 inches, with approximately 9.0 inches being a preferred length. When the overall length of the radiating regions 40A, 40B is approximately 9.0 inches, radiating region 40A will have a length of approximately 7.0 inches, while radiating region 40B will have a length of approximately 2.0 inches. In an embodiment of the air purifier 10 of FIG. 1 where the UV lamp 40 has more than two regions, each additional radiating region of the lamp 40 should have a length of between 2.0 and 10.0 inches, depending on the particular wavelength being emitted by the



additional region. When, in a preferred embodiment, a single wavelength is used, the overall length can be from about 5 inches to 36 inches.

For example, the addition of a radiating region similar to region 40A in FIG. 1 in terms of wavelength produced therefrom should have a length of approximately 2.0 inches, while the addition of a radiating region similar to region 40B in FIG. 1 in terms of wavelength produced therefrom should have a length of approximately 7.0 inches. The addition of a radiating region that produces antimicrobial radiation that is effective to reduce the toxicity of volatile organic compounds should, however, have a length of approximately 9.0 inches.

One of ordinary skill in the art will realize that whichever radiation region is the longest will have the maximum output value, while the other regions will have relative maximum values within their output value ranges.

Now referring to FIG. 2, the lamp outputs defined in arbitrary units are plotted against a portion of the wavelength of the total radiation produced by the lamp 40. The radiating regions 40A and 40B as well as an optional third radiating region, are capable of producing three sets of wavelength maxima 44 and 46 and 48, respectively, within selected wavelength intervals. The first relative maximum lamp output value 46 occurs at or near 185 nm, where the radiating portion 40B preferably emits ozone-producing radiation, within a wavelength band between about 160 nm and about 200 nm. The second maximum output value occurs at or near 254 nm, where the radiating portion 40A preferably emits germicidal radiation, within a wavelength band between about 230 nm and about 280 nm. This is a preferred wavelength region. The third maximum output value occurs at or near 350 nm, where the radiating portion 40C preferably emits antimicrobial radiation that is particularly effective in oxidizing volatile organic compounds (VOCs) to reduce their toxicity, within a wavelength of between about 330 nm and about 360nm.

Those of ordinary skill will readily recognize that the lamp 40 can produce more than three maximum output values by providing a additional radiating regions that also constitute a part of the lamp 40. Additionally, other wavelength intervals can be selected depending upon the desired use of the air purifier. The illustrated lamp has a germicidal radiation producing regions 40A that is approximately three times larger than the ozone-producing

region 40B. This difference in lamp region size is shown by the maximum energy value 44 which is substantially larger than the maximum energy value 46. The preferred lamp 40 is manufactured by Light Sources, Inc., Milford, Connecticut, U.S.A.

Referring again to FIG. 1, additional features of the air purifier 10 are shown mounted on the sidewall 16. A power switch 50 controls the electrical power supplied to the ballast 38 and thus to the lamp 40. A timer control unit 52 allows a user to select a finite operational time for the air purifier 10, and is commercially available from Pass & Seymour, Syracuse, N.Y., U.S.A.

The lamp 40 can be supported or mounted within the eradication chamber 31 by any suitable means, such as by brackets, and preferably includes a pair of lamp sockets (not shown) that are mounted at either end of the lamp. The sockets are conventional items sold by Light Sources, Inc. Titanium catalytic element and mount 41 (see, e.g. FIG. 1B) is useful in supporting lamp 40.

The air flow through the air purifier 10 is generally depicted by the arrows 54, 55 and 56. Specifically, the arrows 54 depict the direction of air flowing into the air purifier and between the air intake chamber 30 and the eradication chamber 31, arrows 55 depict the direction of air flow through the chambers 31 and 32, and arrows 56 depict the direction of air leaving the purifier. During operation of the air purifier, the fan 36 draws inlet air into the air intake chamber 30 through the baffle plates 20 and then into the eradication chamber 31. The air contained within this chamber is then exposed to the UV radiation generated by the lamp 40. This UV radiation preferably has three discrete maximum wavelengths, which serve to destroy microorganisms and to deodorize the air. Element 41 of the air purifier 10 is shaped and placed with respect to the UV lamp 40 and other elements of the air purifier such that the air being treated by the air purifier is able to be fully and freely treated by each radiating region of the UV lamp. As previously described, this treatment is further enhanced by exposure of the air to titanium element 41 within the irradiation chamber. The air then travels through the opening 34 formed in the divider plate 28 into the air exhaust chamber 32 and is then expelled from the air exhaust chamber 32 by the fan 36 through the air outlet 26.

FIG. 3 shows an air purifier 100 according to a second embodiment of the invention. The air purifier 100 includes a housing 102 that includes a front wall 104, a pair of sidewalls

106, and a rear wall (not shown). The front wall 104 preferably has a baffle plate 115 formed thereon. A base 118 supports the front and sidewalls 104 and 106 and the rear wall, and a top plate 120 having a plurality of longitudinal slits 122 defining air intake openings encloses the purifier 100.

5 The purifier 100 mounts a pair of blowers 124 that are electrically connected to a motor 126 by electrical leads 127A and 127B. The UV lamp 40 is supported within an irradiation chamber 132 and is connected by way of electrical lead 134 to a lamp power source 38. The UV lamp 40 of FIG. 3, as well as the lamps shown in FIGS. 4-6, preferably has two UV radiating regions 40A and 40B and that are contiguous and integrally formed, as  
10 described above and is separated by an optical isolator 41 also as described above. The radiating region 40A emits UV radiation having selected germicidal maximum wavelengths and radiating region 40B emits UV radiation having a selected ozone-producing maximum wavelength. Also as described above, the UV lamps 40 of FIGS. 3-6, may have additional radiating regions, each of which may emit radiation having selected germicidal maximum  
15 wavelengths, or selected ozone-producing maximum wavelengths, or selected antimicrobial maximum wavelengths. Further, the optical isolator/element 41 and/or other components of the air purifier of FIGS. 3-6 are preferably made of titanium and titanium-rich alloys as outlined above with respect to FIG. 1. The lamp 40 can be supported within the housing by a variety of fastening means, including element 41 itself. Such a category of exemplary  
20 embodiments is depicted in FIGS. 3A, 4A, 5A, and 6A. Supports may be brackets, and may preferably include a pair of lamp sockets (not shown) mounted at either end of the lamp. The lamp sockets are conventional items and are commercially available from Light Sources, Inc. The blowers 24 and the motor 26 are also conventional and commercially available.

Referring again to FIG. 3, additional features of the air purifier 100 are shown  
25 mounted on, the sidewall 106. A timer 140 mounted on the uppermost portion of the sidewall allows a user to select a finite operational time of the air purifier 100. A power switch 142 mounted beneath the timer controls the power supplied to the purifier. The electrical cord 144, which is connected to the bottom-most portion of the sidewall 106, and the associated plug 146 connect to a conventional 120 volt AC outlet. Alternatively, the plug  
30 146 and the cord 144 can be connected to a 12V/24V DC power source, with slight modifications to the ballast, as is known by those of ordinary skill.

The air flow through the air purifier 100 is generally depicted by the arrows 137 and 139. Specifically, the arrows 137 depict the direction of air flow into the air purifier 100, and the arrows 138 depict the direction of flow of the outlet air. In operation, the blowers 24 draw inlet air into the irradiation chamber 132 of the purifier 100 through longitudinal slits 122. The air contained within the chamber is then exposed to selected levels of UV radiation emitted by the lamp 40. This radiation preferably has two discrete selected maximum wavelength bands, which serve to destroy microorganisms and deodorize the air. The irradiated air is then discharged from the chamber 132 by the blower 124 through the baffle plate 115.

The air purifier 100 can further include a heat exchanger 150, as shown in FIG. 4. The heat exchanger 150 is preferably disposed in the bottom-most portion of the purifier 100, beneath the lamp 40. The heat exchanger 150 has a main body portion 152 that mounts a heating coil (not shown), and has an inlet pipe 153 and an outlet pipe 154. Both pipes 153, 154 are connected to an external water source. The inlet pipe 153 transports hot water from the water source to the heating coil, and the outlet pipe 154 functions as the water returns. Thus, in the illustrated embodiment, the air purifier 100, in addition to purifying air, can function as a heater by providing heat to the external environment.

As shown in FIG. 5, an air conditioning condenser 160 can also be mounted within the housing 102. The illustrated condenser 160 can be supported within the housing by any suitable fastening means, such as by a bracket. The condenser 160 allows the air purifier to cool the surrounding ambient environment. The illustrated air purifier thus provides a versatile and relatively compact multi-functional unit that heats or cools the surrounding environment, as well as purify the surrounding air.

FIG. 6 shows an air purifier 200 according to another embodiment of the invention. The illustrated air purifier constitutes a series of stacked compartments or cells 202 through 208. The cells can be secured together to form a unitary housing 210, and each cell is preferably in fluid communication with each other. The uppermost cell 202 preferably is apertured with a series of longitudinal slits 212 forming air inlet passageways. The cell 204 mounts the lamp 40 and forms an irradiation chamber for exposing the incoming air to the germicidal and ozone-producing radiation of the lamp 40.

The third cell 206 preferably mounts one or more, and most preferably two, filters 214 and 216, as shown. The filter 216 is a conventional particulate filter element that may be purchased from Hepa Corporation, Anaheim, California, U.S.A. A typical filter comprises a plurality of corrugated foil sheets and a cross membrane. The filter 214 is preferably a conventional charcoal filter, and is disposed above the filter 216. In combination, the filters 214 and 216 remove dust particles and odors from the air.

The bottom-most cell 208 preferably mounts a blower 220. The blower draws air into the multi-stacked air purifier through the air inlets 212 and discharges the air through air outlets formed in the bottom cell 208.

In one particular application of this air purifier, among others, the purifier can be connected to the cold air return of the central heating or cooling system of a residential or commercial air circulation system. Thus, the air purifier can continuously filter and purify the air recirculating in the system.

A significant advantage of the present invention is that the lamp 40 mounted within the air purifier produces a maximum radiation output within at least one separate and discrete wavelength interval. Specifically, this interval may be preferably at about 254 nm. Those of ordinary skill will recognize that other embodiments of the inventive air purifier can be attained by varying the geometric shape and arrangement of the housing. Moreover, those of ordinary skill will recognize that a plurality of lamps can be employed, as described below with respect to FIGS. 11 and 11A, where each lamp produces one absolute maximum lamp output value within a selected wavelength interval.

According to another feature of the invention, the air purifiers illustrated in FIGS. 1, and 3 through 6 (and FIGS. 3A through 6A) can be integrated with, or connected to, a pollutant or gas detector which detects the presence of one or more types of gas. As illustrated in FIG. 7, the air purifier of FIG. 1 is coupled to a gas detector 234 to form an air purification and gas detection system 222. Elements of the illustrated air purifier that are common and similar to the elements of the air purifier of FIG. 1 are designated with like reference numerals plus a superscript prime. The illustrated air purifier 10' includes a housing 12' that has a front wall 14' and a rear wall 18'. A set of baffle plates 20' having a plurality of vertical slots 21 are formed in the front and rear walls. A top cover 24' mounts a

handle 25 and has an air outlet 26' formed therein. A fan 36' is mounted in the air outlet passageway 26' to simultaneously draw air into the air purifier and discharge irradiated air therethrough to the external environment.

As previously described, the housing 12' mounts a divider plate 28' and a pair of vertically extending and axially elongated shield plates 29'. The illustrated shield plates 29' are spaced from the baffle plates 20' formed in wall 14' and extend axially along the front and rear walls a selected distance sufficient to cover the slots of the baffle plates 20'. The divider plate 28' and the shield plates 29' separate the interior of the housing 12' into an air intake chamber 30', an irradiation or eradication chamber 31', and an air discharge chamber 32'. As illustrated, the shield plate 29' channels the intake air from the intake chamber 30' into the eradication chamber 31' and further provides a barrier between the external environment and the glare of a UV lamp 40' mounted within the purifier, as described below.

Referring again to FIG. 7, the illustrated divider plate 28' includes an opening 34' formed at one end, e.g., at the end opposite the fan, that allows air to flow between the eradication chamber 31' and the air discharge chamber 32'.

A UV lamp 40' is supported within the eradication chamber 31', illustrated as beneath the divider plate 28', and is electrically connected to a lamp power supply 39'. The power supply 38' preferably includes a ballast and a transformer. The illustrated lamp 40' is identical to the lamp described above in relation to FIGS. 1 and 2, and preferably has a pair of contiguous and integrally formed UV radiating regions 40A' and 40B'. The UV lamp 40', like the lamp 40 in described in FIGS. 1 and 3-6, may have additional radiating regions, each of which is optically isolated from the other radiating regions by a titanium optical isolator 41' and each of which may emit radiation having selected germicidal maximum wavelengths or selected ozone-producing maximum wavelengths, or selected antimicrobial maximum wavelengths. Also as described above, the optical isolator 41' and/or other components of the air purification device of FIG. 7 is preferably made of titanium as outlined above with respect to FIG. 1. The lamp 40' can be supported or mounted within the eradication chamber 31' by any suitable means, such as by titanium brackets or other like fastening mechanisms (e.g. within the spirit of the embodiments of FIGS. 1B and 3A-6A).

The illustrated lamp power supply 38' is electrically coupled via one or more electrical conductors with a power switch 50' that is mounted on sidewall 16' of the illustrated air purifier. The power switch 50' controls the power supplied to the ballast 39' from an external power source, and thus to the lamp 40'. A timer control unit 61 is mounted to one of the baffle plates 20' and is also electrically coupled to the power supply 38' via electrical conductors (not shown) and to a timer control switch 53 mounted adjacent the power switch 50' on the sidewall 16'. The timer switch in conjunction with the timer control 61 allows a user to select a finite operational time for the air purifier 10'.

An external power source 235 supplies power via a power cord 89 to the air purifier 10'. The illustrated power cord is preferably coupled to the lamp power supply 38' via separate electrical conductors (not shown).

Referring again to FIG. 7, the illustrated gas detector 234 is preferably mounted between the external power source 235 and the air purifier 10' and is directly coupled to the power cord 89. The gas detector 234 can be any conventional gas detector of the type compatible for use with the present invention, and which can detect a variety of gases, such as carbon oxides, e.g., carbon monoxide and carbon dioxide, hydrogen, oxygen, ethanol, propane, butane, methane, formaldehyde, sulphur dioxide, hydrogen sulfide, NO<sub>x</sub>, ozone, benzene, radon, and aerosols and other toxic or health threatening gases or vapors including a broad variety of organic vapors. In the illustrated embodiment, the gas detector includes a pair of electrical adaptors 91 that are arranged for insertion into a pair of corresponding electrical apertures of the type typically formed in a conventional wall outlet 235. Gas detectors of the type shown and described are available from several manufacturers, including Pama Electronics Co. Ltd., Oceanside, NY, U.S.A. According to one practice of the invention, the gas detector senses the presence of a selected gas in the surrounding air. If the detected level of gas is above a selected level, which can be predetermined or selected according to the exigencies of the situation and/or the particular mode of operation of the detector, the detector 234 generates an output signal indicative of the presence of the excess quantities of the selected gas. The detector 234 can also actuate an audible alarm and/or a visual alarm to alert an occupant of the presence of the gas.

In operation, and as illustrated by the block arrows illustrated in FIG. 7, air flows into the air purifier 10' through the baffle plate slots 21 and travels between the front panel 14' and the shield plate 29 which define the air intake chamber 30'. The air is drawn into the air purifier by the operation of the fan 36'. The air then flows from the air intake chamber 30' into the eradication chamber 31' where it is exposed to UV radiation emitted by the lamp 40'. The irradiated air then travels through the opening 34' formed in the divider plate 28' and into the air exhaust chamber 32', where it is expelled through the air exhaust passageway 26' by the fan 36'.

Additionally, the integrated gas detector 234 selectively actuates the air purifier 10' to remove or reduce the levels of selected contaminants e.g., one or more gases, from the surrounding air. For example, if the gas detector senses the presence of a selected gas in concentrations (typically measured in parts per million (ppm)) above a selected level, the detector generates an output signal that is transferred to the air purifier power supply 38' along power cord 89 and other associated wiring. The output signal generated by the gas detector actuates the air purifier, which in turn purifies the surrounding air for a selected period of time. According to one practice, the gas detector output signal activates the air purifier for a selected time period, e.g., 40 minutes, to remove or reduce the levels of gas in the surrounding air. Concomitantly, the gas detector 234 continues to monitor the levels of gas in the air to ensure that the levels do not remain above a selected level. If the gas levels remain above the selected level, e.g., due to a malfunction in the operation of the air purifier, an audible and/or visual alarm can be activated by the detector, in addition to maintaining, if desired, the operation of the air purifier.

The gas detector and the air purifier can cooperate in a number of ways to effect the necessary removal of pollutants from the air that are sensed by the detector. For example, the ballast circuit can include switching circuitry that activates the lamp in response to the output signal generated by the gas detector.

A significant feature of the present invention is that the integration of the gas detector with the illustrated air purifier forms an automatic and modular gas detection and removal system that continuously or periodically samples the surrounding air for a selected gas and



removes the selected gas therefrom when the sensed gas level is beyond a predetermined range.

FIG. 8 shows an alternate embodiment of the air purifier system 222 of FIG. 7. Elements of that system that are common and similar to the elements of the embodiment of FIGS. 1 and 7 are designated with like reference numerals plus a superscript prime. Titanium element 41 may be incorporated as a bracket (e.g. FIG. 1B, etc.) or as an optical isolator (e.g. FIG. 1A, etc.) The illustrated system 222 includes an integrated gas detector 234' that is mounted to or on the air purifier housing 12'. Thus, the gas detector need not be adapted for direct insertion into a conventional wall outlet, but rather can be mounted directly to the air purifier unit 10', thus allowing the use of more conventional gas detectors.

The illustrated gas detector can also be coupled with the air purifier via radio frequency electromagnetic waves. According to one practice, the gas detector includes an integrated radio frequency (RF) transmitter. The air purifier has mounted thereon a radio frequency receiver for receiving radio frequency output signals generated by the RF transmitter portion of the detector. During operation, the gas detector generates and emits an RF output signal when the detector senses gas concentrations outside of a predetermined range. The output signal is transmitted as a radio frequency signal and is received by the RF receiver mounted in or on the air purifier. Thus, a gas detector can be remotely located from the air purifier without the necessity of coupling the two with hard wiring.

FIG. 9 illustrates an alternate embodiment of the air purifier of the invention. The illustrated air purifier 300 is typically employed in commercial environments which require greater quantities of air to be processed and purified. The illustrated air purifier 300 includes a substantially cylindrical housing 302, a bottom portion 304, and a top portion 306. The top portion 306 mounts a handle 310 which assists the user in handling the purifier. The cylindrical housing 302 has formed thereon a plurality of axially spaced rows of apertures 312 defining air inlets, similar to the baffle plates of FIGS. 1 and 7-8. The interior of the purifier mounts a cylindrical divider element 322 that separates the interior of the housing into an air intake chamber 314 and an eradication chamber 318. The illustrated divider 322 has an opening 326 formed in one end that allows air to flow between the inlet passageway 314 and the eradication chamber 318. A UV lamp 40' is supported within the eradication

chamber by a pair of support stanchions 320,320 that are coupled to the inner surface 324 of the divider.

A blower 330 is disposed in the bottom portion of the housing 302. The illustrated blower 330 has a plurality of radially extending blades 332 which rotate in a selected manner to draw air into the interior of the air purifier while simultaneously discharging air through an air outlet 336 formed in the bottom of the housing 302. A lamp power supply 340 similar to the power supply 38 of FIGS. 1 and 7-8 provides a selected level of operating power, typically supplied by a conventional wall outlet, to the lamp 40'. The purifier housing 302 has mounted thereon a power switch 344 for controlling the electrical power supply to the ballast 38, and thus to the lamp 40'.

In operation, air is introduced through the air inlets 312, 312 by the operation of the blower 330, which is denoted by the block arrows. The air is then carried along the air inlet chamber 314 and into the eradication chamber 318, where the UV lamp irradiates the air for a time sufficient to purify the air. The fan 330 then discharges the irradiated air through the air outlet 336 located in the bottom of the purifier.

FIG. 10 illustrates another embodiment whereby the air purifying apparatus of the invention is integrated with a heating/ventilation/air conditioning (HVAC) unit. The illustrated HVAC unit 400 can be a conventional heating system that employs a return air duct 404, a furnace portion 406, and a discharge air duct 408. The furnace portion 406 of the HVAC 400 can include a blower unit 410 to heat or cool single or multiple zones in a building structure. The blower unit 410 has an electrical output lead 432 that terminates in a terminal block 434.

The illustrated air purifying device of the invention is mounted in the return or supply air duct 404 of the HVAC unit 400. The air purifying device 420 includes a hinged control panel 422 that has an exposed surface panel 424 and an inner surface 426 that mounts a UV lamp 40' via a pair of support stanchions 430. The illustrated lamp is identical to the lamp previously described. The mounting of lamp 40' inside the return air duct 404 effectively creates an eradication chamber that purifies air passing therethrough.

An electrical power cord 436 is connected electrically in series with the terminal block 434 and the control panel 420. The power cord terminates at a coupling connector 438 formed in the control panel. The lamp 40' and the power cord 436 are coupled via appropriate electrical wiring with an electronic ballast circuit assembly 440 mounted on the inner surface 426 of the panel 420. An electrical power switch 442 functioning as an on/off switch operates the lamp 40' by selectively applying power to the lamp.

The illustrated control panel 420 further includes a sight glass aperture 450 that extends between the exposed and inner surfaces of the control panel 420. The sight glass allows an individual to view the interior of the return duct 404 to check whether the lamp 40' is functioning. A power fuse 452 can further be employed to protect the electronic circuitry associated with the panel 420 and the lamp 40' from overvoltage and/or overcurrent conditions.

In operation, the blower 410 circulates air between the return air duct 404 and the air duct 408, and thus between the HVAC unit and one or more zones within the building. As air is drawn through the return air duct 404, it is irradiated by UV radiation generated and emitted by the lamp 40' mounted therein. The irradiated air exits the return duct 404 and is discharged through the air duct 408 by the blower 410. Thus, the illustrated air purifying device purifies air located in a particular zone of a building.

Those of ordinary skill recognize that a gas sensor can also be integrated with the air purifying device for HVAC units as illustrated in FIG. 10 in accordance with the description set forth in relation to FIGS. 7 and 8. According to one practice, the gas detector can continuously monitor the air flowing throughout the HVAC system to determine if a particular gas is present therein. If so, the gas detector can generate an output signal that actuates the air purification device 420. The operation of the air purifier 420 serves to purify the air passing through the HVAC system by removing or reducing the levels of a particular gas. Optionally, the detector can sound an alarm when the detected gas concentration is greater than a predetermined threshold value or range. In severe situations, the air purification device 420 can turn off the furnace and continuously operate the air purifier, e.g., the UV lamp 40', while actuating the blower unit 410 to continuously circulate air throughout

the system. The furnace is then restarted once the levels of the detected gas are within an allowable range of values.

The illustrated lamp can also be mounted in other locations besides the return air duct, such as the discharge duct 408.

5           Additionally, the commercial air purification embodiment of FIG. 9 can further include a gas detector as described above in relation to FIGS. 7 and 8. Further, FIGS. 9A and 10A depict titanium elements 41 as brackets instead of optical isolators.

10           In another embodiment of the present invention depicted in FIG. 11 the air purifiers of FIGS. 1 and 3-6 of the air purification device of FIG. 7 can mount a plurality of radiation sources, such as UV lamps, wherein each UV lamp has a plurality of radiating or radiation regions, each of which produces a radiation having a maximum energy value that falls within a different wavelength band. Specifically, each radiating region is capable of generating a first energy maximum of ozone-producing radiation and a second separate energy maximum of germicidal radiation and a third separate energy maximum of antimicrobial radiation.

15           The preferred number of radiating regions in each of the plurality of radiation sources is two, wherein one of the two regions generates ozone-producing radiation and the other region produces a second separate energy maximum of germicidal radiation. Each radiation region does not, however, necessarily have to have the same number of radiating regions nor do the radiating regions of each of the radiation sources have to produce the same types of  
20           radiation. For example, in an embodiment with three radiation sources, two of the sources could have two radiating regions which generate, respectively, ozone-producing radiation and a separate energy maximum of germicidal radiation, while the third radiation source produces ozone-producing radiation in the range of about 160 nm to about 200 nm, a separate energy maximum of germicidal radiation in the range of about 230 nm to about 280 nm, and a  
25           separate energy maximum of antimicrobial radiation in the range of about 330 nm to about 360 nm.

The plurality of radiation sources are arranged such that they may fit within the air purifier. One of ordinary skill in the art will realize that the dimensions and/or the positional relationships between the elements of the air purifiers of FIGS. 1 and 3-6 and the air

purification device of FIG. 7 may have to be slightly changed in order to accommodate the increased space required to accommodate a plurality of radiation sources; however, the elements included in the air purifier remain the same.

FIG. 11 and FIG. 11A show exemplary embodiments of this multiple radiation source embodiment wherein four radiation sources W, X, Y and Z are present. As shown each of the radiation sources W, X, Y, and Z is preferably a UV-producing lamp similar in shape and type to those depicted in the FIGS. 1 and 3-7 embodiment of the present invention. While, generally, the radiation sources are lamps of this shape and type, one of ordinary skill in the art will realize that other radiation sources and/or shapes and types of UV-producing lamps may be utilized in place of or in conjunction with the lamps depicted in FIG. 11. Also, the number of radiation sources in these embodiments may be greater or less than four as long as the number is greater than one.

In the FIG. 11 embodiment, each radiation source W, X, Y, and Z is preferably prevented from producing radiation that may interact with radiation emitted from any of the other radiation sources through the usage of titanium optical isolator 41 such as those depicted in and described with respect to FIGS. 1 and 3-7. In the FIG. 11A embodiment, elements 41 are shown separating the sources; however specific/distinct radiation regions denoted R, S, T are not isolated by element 41.

In the arrangement depicted in FIG. 11, the titanium optical isolator 41 allows air to circulate through the radiation sources W, X, Y and Z, while preventing the UV radiation emitted from each source from “seeing” the radiation produced from any of the other radiation sources. One possible path for air to travel is indicated by the arrows of FIG. 11. The above-summarized arrangement of radiation sources in FIG. 11, just as in FIGS. 1 and 3-7, allows the radiation sources to work in tandem, with each source producing radiation without being hampered by “seeing” other radiation.

As noted above, one of ordinary skill in the art will readily ascertain that such an arrangement scheme may be carried out with any number of radiation sources greater than one (i.e., fewer or greater than four sources) wherein each source has at least two radiating or radiation regions. Optimally, each radiating region is optically isolated from the other radiating regions of that particular radiation source as well as each of the radiating regions of

the other radiating sources to form individual radiation chambers through which air may freely travel and be treated by the particular wavelength emitted from the radiation region in that radiation chamber. One of ordinary skill in the art, however, will realize that it is possible for the any or all of the FIG. 1, 3-7 and 11 embodiments of the present invention to effectively treat air wherein one or more of the radiating regions of the one or more radiation sources are not optically isolated from each other.

In an exemplary embodiment of FIG. 11, each of the four UV lamps W, X, Y, Z has three radiation regions R, S and T. (In FIG. 11A, two radiation regions S and T are denoted.) For example, radiation source W is depicted as having radiation regions R, S and T, wherein region R emits ozone-producing radiation in the range between about 160 nm to about 200 nm, while region S emits germicidal radiation in the range between about 230 nm to about 280 nm, while region T emits antimicrobial radiation in the range between about 330 nm to about 360nm.

Like the embodiments shown and described with respect to FIGS. 1 and 3-7, each of the titanium optical isolator 41 for each of the radiation regions R, S and T of each of the radiation sources W, X, Y, and Z of FIG. 11 is preferably a barrier or baffle made, at least partially, of titanium, platinum or gold.

Constructing the optical isolator/element 41 out of titanium is also desirable due to the presence of titanium acting to enhance the effects of the wavelengths of each of the radiating regions 40A, 40B or the UV lamp 40 thus producing hydroxyl and other oxygen-containing free radicals.

For example, if the optical isolator 41 is made of titanium, then air that passes through the air purifier 10 and the titanium optical isolator will react in the presence of the emitted UV radiations and undergo a photocatalytic reaction wherein molecular oxygen that is present in the air will react with the titanium to break down other constituents of the air and to create oxide ions and/or hydroxyl radicals that will convert carbon monoxide in the air to carbon dioxide, and to increase the destruction and/or reduction of the levels of bacteria, virus, mold, mildew, fungus and volatile organic compounds in the air by, for example, oxidizing them and/or causing the formation of water vapor.

The optical isolator 41 may also be coated with other elements and/or compounds (i.e. platinum or gold) in order to more effectively and/or more efficiently reduce or destroy unwanted components of the air being treated by the air purifier 10. Among these elements or compounds are silver compounds or oxides, copper compounds or oxides, microcrystalline titanium or titanium dioxide. These compounds may be applied to the air purification system via a coating either on, near or entirely separate from the optical isolator 41. The presence of these elements or compounds will assist any photocatalytic reactions taking place in the air purifier 10 as summarized in the teachings of U.S. Patent Nos. 5,759,948 to Takaoka et al. and 5,835,840 to Goswami, both of which is expressly incorporated by reference herein.

Oxides of titanium provide particularly effective coatings designed to promote photocatalysis. Significant enhancement of the photocatalytic reactions that take place as air flows over such a coating in the presence of ultraviolet radiation is thought to occur irrespective of which of the various crystallographic forms of titanium oxide is used. As a result, optical isolator/element 41 and/or other surfaces exposed to the air within air purifier 10 on, near or entirely separate from optical isolator/element 41, in an embodiment, are fabricated from elemental titanium metal or a titanium-rich alloy.

Commercially pure titanium is an excellent oxygen getter under most environmental conditions. As a result, titanium and titanium-rich alloys naturally maintain an oxide-containing film upon its metallic surface. Adherence of this surface film is particularly tenacious. Further, this oxide-containing surface layer will tend to reform as it is used up and fresh metallic surfaces are exposed to the air as the chemical reactions with the air and impurities therein proceed. Thus, these parts of air purifier 10 may only require infrequent cleaning or replacement.

One of ordinary skill in the art will readily ascertain that the usage of titanium and/or titanium dioxide and/or any of the above-indicated elements or compounds may be slightly modified while still providing for improved performance of the system. Furthermore, the usage of titanium and/or titanium dioxide and/or any of the above-indicated elements or compounds may also be possible in conjunction with the embodiment depicted in FIG. 1.

The invention is further illustrated by the following Examples 1 and 2, which should not be construed as further limiting. Example 1 illustrates the efficacy of the air purification

system of the present invention in removal of toluene from the air, as well as the inactivation of *E. coli* and common bakers yeast. FIGS. 12 and 13 are graphical representations of the removal of toluene from the air as a function of time with and without UV exposure, respectively. FIG. 14 is a plot of *E. coli* inactivation with time; FIG. 15 is a plot of bakers yeast inactivation with time. Removal of acetone has also been successfully shown utilizing the same air purification system; this result is described in Example 2. FIG. 16 is a graphical representation of the removal of acetone from the air (with UV exposure) as a function of time. The specifications for the air purification system used in Examples 1 and 2 are:

20 W power,

a 254 nm UV radiation lamp,

the lamp mounted on a scored titanium bar in flexible duct tubing (33 cm diameter and 80 cm in length.

The ducting was fed with a 500 cpm fan. The output intensity (fluence rate or irradiance) of the lamp at 16 cm distance from the lamp was  $16 \text{ W cm}^{-2}$  ( $1.6 \text{ W m}^{-2}$  or  $4 \text{ mol cm}^{-2} \text{ s}^{-1}$ ). This is a high level of UVC radiation. This entire system was placed inside a sealed laboratory fume hood (dimensions; 160 cm w x 110 cm h x 60 cm d). When the system was operating, there was no scent of  $\text{O}_3$  present. This system was analyzed for its ability to destroy both a model VOC and to inactivate microbes.

### EXAMPLE 1

Toluene analysis: Toluene (40 ml or 35g) was placed in a 25 cm evaporating dish and the dish was placed in the hood near the 500 cfm fan and left there for 2 h with the fan on. This allowed the hood ( $4 \text{ m}^3$ ) to be saturated with 35 g of toluene giving an initial concentration of  $7 \text{ gm}^3$  (i.e.  $\sim 2000 \text{ ppm}$ ). This toluene concentration was stable for at least 4 h (see results). Toluene was then collected for HPLC analysis by bubbling air from the hood through 5 ml of dichloromethane (DCM). Bubbling was carried out for 3 min. The bubbling system had a glass funnel as the inlet placed inside the duct tubing. The funnel was connected to tygon tubing linked to a peristaltic pump. The tubing was attached to a glass pipette immersed in the DCM. The UVC lamp was then switched on and an air



sample was collected after 1, 2, 3 and 4 h. For a dark control, the UVC lamp was left off. Toluene analysis was performed with a Shimadzu dual pump HPLC with a diode array detector. A water to DCM gradient was used to elute the toluene, and toluene identification was confirmed by retention time and absorbance spectrum. All experiments were performed in duplicate.

Microbial analysis: *E. coli* and common bakers yeast were cultured by standard methods in liquid medium. They were sprayed in the hood and allowed to be circulated by the 500 cfm fan for 1 h. Microbes were collected on agar growth medium in standard petri dishes. They were collected at 0, 1, 2, 3, and 4 h with the UVC lamp either on or off.

The plates were then incubated overnight at 37 C for the *E. coli*, room temperature for the yeast. Colonies were counted on the plates to determine titers. All experiments were performed in duplicate.

Toluene degradation: Toluene, when incubated with the fan on in darkness was maintained nearly at the initial concentration (~2000 ppm). The  $t_{1/2}$  (half-life) was more than 16 h based on the "toluene in darkness" plot of FIG. 13. This shows that the toluene was not lost rapidly from the test system merely because the 500 cfm fan was on.

When toluene was incubated in the photocatalytic air purifier with the fan and the UVC lamp on, the toluene was rapidly lost (see FIG. 12). It is assumed that the toluene is lost due to photochemical degradation (probably oxidation). The toluene was consumed by apparent exponential decay kinetics (pseudo first-order kinetics), with a  $t_{1/2}$  of 1.85 h. This is described by the following equation:

$$[\text{toluene}]_t = [\text{toluene}]_0 e^{-kt}$$

where:  $[\text{toluene}]_t$  is toluene at time  $t$ ,

$[\text{toluene}]_0$  is toluene at time 0,

$k$  is the first order rate constant, and  $t$  is time in hours.

Based on a  $t_{1/2}$  of 1.85 h,  $k = 0.37 \text{ (h}^{-1}\text{)}$

*E. coli* inactivation: *E. coli*, when incubated with the fan on in darkness was

maintained at constant level (data not shown). When *E. coli* was incubated in the test system with the fan and the UVC lamp on, the bacteria were rapidly inactivated (see FIG. 14). It is assumed that the bacteria were killed by the UVC radiation (probably due to DNA damage) because 254 nm is near the peak absorbance of DNA. Like the toluene, the bacteria were inactivated by apparent exponential decay kinetics with  $t_{1/2} = 1.4$  h. Using the above equation,  $k = 0.49$  ( $\text{h}^{-1}$ ). Thus, bacterial inactivation is somewhat faster than consumption of toluene. This is not surprising since microbes are known to be hypersensitive to UVC.

Yeast inactivation: Yeast was used as a model eukaryotic microbe representing fungi and molds. The results with yeast were very similar to those with the bacteria. Yeast, when incubated in the photocatalytic air purifier with the UVC lamp on, were rapidly inactivated (See FIG. 15). As above, apparent exponential decay kinetics was observed. The  $t_{1/2}$  was 1.05 h and  $k = 0.66$  ( $\text{h}^{-1}$ ). Thus, yeast was inactivated faster than *E. coli*. This may reflect the greater DNA content of eukaryotic organisms. Because both *E. coli* and yeast were inactivated rapidly, it may reasonably be extrapolated that all microbial organisms will be neutralized by the photocatalytic system tested.

Thus, the experiment of Example 1 demonstrates that: (1) the half-lives for loss of toluene, *E. coli* and yeast were 1.85 h, 1.4 h and 1.05 h, respectively; (2) the photocatalytic air purifier should remove more than 90% of the toluene in about 8h; (3) microbes are inactivated by the photocatalytic air purifier more rapidly than the toluene is degraded; and (4) 90% of the microbes would be inactivated in 6 h or less with the system employed.

## **EXAMPLE 2**

A similar study (to Example 1) was undertaken to test performance of the air purification system in removing acetone (dimethyl ketone). The acetone was rapidly removed (see FIG. 16). The acetone half-life was 0.60 h; therefore, the decay constant,  $k = 1.15$  ( $\text{h}^{-1}$ ). This is about twice the rate of removal of toluene detailed in Example 1.